1854MNRAS..15...36A

positions of the two pendulums, any difference in their rate of oscillation being thereby completely eliminated. Secondly, there was the comparison of each pendulum with its clock ; this object was attained by employing the method of coincidences originally suggested by Captain Kater. Thirdly, an accurate comparison of the clock at the bottom of the mine with the clock at the top was indispensable. This was by far the most difficult part of the operations. In the Dolcoath experiment this object was effected by the very inconvenient process of carrying chronometers from the top of the mine to the bottom along a series of ladders. The application of galvanism to astronomical observations had suggested to the President the advantage of comparing the two clocks by effecting a galvanic connexion between them. This is accordingly the method which has been practised in the Harton Colliery experiments : it would be hardly necessary to add that it was, in every respect, superior to any other mode of comparison. The President finally remarked, that until all the necessary calculations were worked out, it was impossible to ascertain the definitive result of the experiments.

Note on the Origin of the Attempts made in the seventeenth Century to derive from physical Principles an invariable Standard of Measure. By the Editor.

The only physical standards of measure, which have been applied to astronomical and other scientific purposes in modern times, are those which have heen furnished by the oscillations of the pendulum and the length of an arc of the meridian. This note is accordingly confined to some remarks on the origin of these two methods.

The pendulum seems to have *first* suggested itself to scientific men as capable of furnishing a permanent standard of measure. Sprat, in his History of the Royal Society (1667), enumerating the inventions and discoveries due to one or other of the Fellows of the Society, mentions the invention of "*a universal standard or measure of magnitudes by the help of a pendulum, never before attempted.*"—(4th Edition, p. 247). In a subsequent part of the same work the author gives a special account of the labours of Dr. (afterwards Sir Christopher) Wren, in the course of which he states that the latter had shown "*that there may be produced a natural standard for measure from the pendulum for vulgar use.*"—(p. 314.)

I am not acquainted with any author who has since alluded to the labours of Wren or any other Fellow of the Royal Society in connexion with this subject. The primary idea of employing the oscillations of the pendulum to obtain a standard of measure is not generally adverted to by scientific writers. Delambre, in his Analysis of the *Horologium Oscillatorium*, pub-

1854MNRAS..15...36A

lished in 1673 (*Hist. Art. Mod.* vol. ii.), notices the proposal of Huyghens to establish an invariable standard of measure on the basis of the oscillations of the pendulum; but he does not assert that the suggestion of such a measure was due to the Dutch philosopher. On the contrary, he refers to a somewhat similar proposal made by Mouton in his work — *Observationes Diametrorum Solis et Lunæ*, Lugd. 1670. It has, however, been recently asserted, although in somewhat obscure terms, upon the strength of the passage in the *Horologium Oscillatorium*, above alluded to, that the invention is really due to Huyghens. This point will be best ascertained by citing the words of the author himself. Referring to the advantage of a knowledge of the centre of oscillation, in finding the length of the pendulum, he thus remarks:—" Hinc necesse fuit illis, qui, ante hanc centri oscillatorii determinationem mensuræ universalis constituendæ rationem inierunt; *quod, jam inde à prima Horologii nostri inventione, nobilis illa Societas Regia Anglicana sibi negotium sumpsit* et recentius doctissimus Astronomus Lugdunensis, Gabriel Moutonus; his, inquam, necesse fuit designare globuli suspensi diametrum, vel proportione certa ad fili longitudinem cujus nempe tricessimam vel aliquam partem æquaret." — (*Horologium, Pars Quarta*, Prop. xxv.) It appears clearly from the foregoing passage that the idea of deriving an invariable standard of measure from the oscillations of the pendulum originated with the Royal Society, having been suggested to some of the Fellows by Huyghens' application of the pendulum to clocks.

Having recently had occasion to examine the MSS. of the Royal Society, I availed myself of the privilege so liberally accorded to me by that body, to ascertain if any records existed of the early labours of the Society in connexion with the establishmont of an invariable standard of measure. In this research I was not disappointed. The following extract of a letter from Huyghens to Sir Robert Moray, dated the Hague, Dec. 30, 1661, confirms the statement above cited from the *Horologium Oscillatorium:* " La fabrique de ma machine [pneumatique] m'a empeché quelque temps de travailler aux traités dont vous me demandez de nouvelles. J'ai entre les mains celui de l'horloge, duquel une grande partie est dediée aux mouvements, *et particulièrement j'y ai parlé de cet usage du pendule pour la mesure universelle, dont vous dites qu'on a traité dans votre assemblée.*" (*Letter Book*, vol. i. p. 22.)

Upon referring to the *Journal Book* of the Royal Society, I found that the question of an invariable standard of measure, founded on the oscillations of the pendulum, had been discussed at several of the meetings of the Society, towards the close of the year 1661 and the beginning of the following year. At the meeting, held on the 22d of January, 1662, it is stated that the President, Lord Brouncker, "introduced the history and schemes of the pendulum experiment, and that a committee, consisting of the President, Mr. Boyle, Sir William Pettey, Dr. Wilkins, and

1854MNRAS..15...36A

Dr. Wren, was appointed to make trials of it." (*Journal Book*, vol. i. p. 46.)

It would appear that the experiments of the Committee were not successful, for, at the meeting held on Feb. 5, 1662, "*Dr. Wren was entreated to think of an easy way for a universal measure, other than the pendulum.*" (*Journal Book*, vol. i. p. 48.)

Viewing the statement of Sprat, in connexion with this passage, it appears extremely probable that Wren was the first who proposed the deriving a standard of measure from the oscillations of the pendulum. The idea was, indeed, worthy of the genius of that distinguished man.

The difficulties experienced by the Committee, doubtless, arose from their ignorance of the centre of oscillation of the different pendulums, as well as from the disturbing effects of the resistance of the air and various other causes.

At length the discovery of a method for determining the centre of oscillation by Huyghens, removed what was considered to be the sole impediment to the success of the pendulum experiment in furnishing an invariable standard of measure. Huyghens announced his discovery in a letter to Sir Robert Moray, dated Nov. 21, 1664. He gives the rule for finding the centre of oscillation of a pendulum, consisting of a homogeneous spherical ball, suspended by a thread or wire. He states that for a pendulum oscillating half-seconds, he found by calculation that the distance between the point of suspension and the centre of oscillation was exactly 9½ inches, Rhinland measure. (*Letter Book of the Royal Society*, vol. i. p. 225.)

The letter of Huyghens, above referred to, was read at the meeting of the Royal Society, on the 23d of November, 1664. In the *Journal Book* it is simply recorded that the letter was read; but there is evidence to show that the discovery, announced by Huyghens, was justly appreciated by the Society. Oldenburg, in a letter to Boyle, dated Dec. 3d, 1664, states that when the letter of Huyghens was read to the Society, "order was given that it should be punctually registered, to the end that Mr. Huyghens might have his due, and his inventions recorded for his honour to posterity." (Boyle's Works, vol. v. p. 328.)

The Society lost no time in verifying the theorem of Huyghens, respecting the centre of oscillation, by making experiments with pendulums of different lengths, and employing oscillating spheres of different magnitudes. In the first experiments with pendulums, oscillating in half-seconds, the theorem of Huyghens was found to "*be very near the truth.*" In the second series of experiments, when the oscillations of the pendulum were performed in seconds, it was found on one occasion that the string, with the smaller sphere attached to it, was $\frac{1}{10}$ *longer than it ought to have been, according to Huyghens' theorem.* A similar result was obtained in other instances wherein spheres of different magnitudes were employed. This inconsistency between theory and the results of actual experiment was attributed to the resistance of the air.

1854MNRAS..15...36A

Thus, notwithstanding the beautiful discovery of Huyghens, respecting the centre of oscillation, it was found that the oscillations of the pendulum could not be confidently employed in furnishing an invariable standard of measure. Hooke, who, probably, felt somewhat piqued, on account of the small share which he had in the inquiry, was the most strenuous objector to the use of this method. He remarked, among other disadvantages which would accompany its practical application, that if, as was in all probability the case, the force of gravity increased in intensity from the equator to the poles, it would necessarily follow that *in proceeding from the equator towards either of the poles, the oscillations of the seconds' pendulum would gradually be quickened.* This suggestion, so characteristic of the genius of Hooke, was announced to the Royal Society nine years previous to the return of Richer from Cayenne.*

Mouton (*Observationes Diametrorum*, &c., 1670) appears to have first proposed the length of an arc of the meridian as the basis of an invariable standard of measure. In the Appendix, p. 427, he suggests a decimal system of measures, the fundamental unit of which he proposes to derive from the value of a minute in Riccioli's length of a degree of the meridian; and he finds the unit of measure † thus obtained to be equal to the length of a simple pendulum, which makes 1252 oscillations in half-an-hour.

I am indebted to Mr. Sheepshanks for the foregoing statement respecting the proposal of Mouton to derive a standard of measure from the length of an arc of the meridian, not having myself seen the work in which reference is made to that method. ‡

It was soon suspected, as in the case of the pendulum, that the method of deriving a standard measure from the length of an arc of the meridian might be liable to serious objections. At the meeting of the Royal Society, held on the 7th of June, 1682, when the question of measuring an arc of the meridian in England was discussed, the President (Sir Christopher Wren) remarked that, according to his opinion, the best standard of measure "would be a certain part of the length of a degree upon the earth, *if at least upon several accurate trials of the measure of a degree in several latitudes it should be found the same, and not different, as it would be if the body of the earth were oval and not perfectly globular.*" (*Journal Book*, vol. vii. p. 86.)

It appears somewhat strange that it did not occur to any one that the supposed defects of the methods based upon the pendulum and the length of an arc of the meridian might be obviated by confining the experiments and observations to a fixed latitude.

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* Hooke's objections to the use of the pendulum, in furnishing an invariable standard of measure, were stated at the meeting of the Society, held on Dec. 14, 1664.

† Termed by him *the Virga*; it was equal to the thousandth part of the length of a minute of Riccioli's arc.

‡ Delambre has justly remarked that Mouton's work is very rare.